XVI. *New Experiments on the Ocular Spectra of Light and Colours. By* Robert Waring Darwin, *M. D.*; *communicated by* Eraſmus Darwin, *M. D. F. R. S.*

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WHEN any one has long and attentively looked at a bright object, as at the ſetting ſun, on cloſing his eyes, or removing them, an image, which reſembles in form the object he was attending to, continues ſome time to be viſible: this appearance in the eye we ſhall call the ocular ſpectrum of that object.

Theſe ocular ſpectra are of four kinds: 1ſt, Such as are owing to a leſs ſenſibility of a defined part of the retina; or *ſpectra from defect of ſenſibility*. 2d, Such as are owing to a greater ſenſibility of a defined part of the retina; or *ſpectra from exceſs of ſenſibility*. 3d, Such as reſemble their object in its colour as well as form; which may be termed *direct ocular ſpectra*. 4th, Such as are of a colour contrary to that of their object; which may be termed *reverſe ocular ſpectra*.

The laws of light have been moſt ſucceſsfully explained by the great NEWTON, and the perception of viſible objects has been ably inveſtigated by the ingenious Dr. BERKELEY and M. MALEBRANCHE; but theſe minute phænomena of viſion have yet been thought reducible to no theory, though many philoſophers have employed a conſiderable degree of attention upon them: among theſe are Dr. JURIN, at the end of Dr. SMITH's Optics; M.

ÆPINUS, in the Nov. Com. Petropol. V. 10.; M. BEGUELIN, in the Berlin Memoires, V. II. 1771; M. D'ARCY, in the Hiſtoire de l'Acad. des Scienc. 1765; M. DE LA HIRE; and, laſtly, the celebrated M. DE BUFFON, in the Memoires de l'Acad. des Scien. who has termed them accidental colours, as if ſubjected to no eſtabliſhed laws, Ac. Par. 1743. M. p. 215.

I muſt here apprize the reader, that it is very difficult for different people to give the ſame names to various ſhades of colours; whence, in the following pages, ſomething muſt be allowed if, on repeating the experiments, the colours here mentioned ſhould not accurately correſpond with his own names of them.

I. ACTIVITY OF THE RETINA IN VISION.

From the ſubſequent experiments it appears, that the retina is in an active not in a paſſive ſtate during the exiſtence of theſe ocular ſpectra; and it is thence to be concluded, that all viſion is owing to the activity of this organ.

1. Place a piece of red ſilk, about an inch in diameter, as in fig. 1. (Tab. IX.) on a ſheet of white paper, in a ſtrong light; look ſteadily upon it from about the diſtance of half a yard for a minute; then cloſing your eyelids cover them with your hands, and a green ſpectrum will be ſeen in your eyes, reſembling in form the piece of red ſilk: after ſome time, this ſpectrum will diſappear and ſhortly re-appear; and this alternately three or four times, if the experiment is well made, till at length it vaniſhes entirely.

2. Place on a ſheet of white paper a circular piece of blue ſilk, about four inches in diameter, in the ſunſhine; cover the center of this with a circular piece of yellow ſilk, about

three inches in diameter; and the center of the yellow ſilk with a circle of pink ſilk, about two inches in diameter; and the center of the pink ſilk with a circle of green ſilk, about one inch in diameter; and the center of this with a circle of indigo, about half an inch in diameter; make a ſmall ſpeck with ink in the very center of the whole, as in fig. 2.; look ſteadily for a minute on this central ſpot, and then cloſing your eyes, and applying your hand at about an inch diſtance before them, ſo as to prevent too much or too little light from paſſing through the eyelids, you will ſee the moſt beautiful circles of colours that imagination can conceive, which are moſt reſembled by the colours occaſioned by pouring a drop or two of oil on a ſtill lake in a bright day; but theſe circular iriſes of colours are not only different from the colours of the ſilks abovementioned, but are at the ſame time perpetually changing as long as they exiſt.

3. When any one in the dark preſſes either corner of his eye with his finger, and turns his eye away from his finger, he will ſee a circle of colours like thoſe in a peacock's tail: and a ſudden flaſh of light is excited in the eye by a ſtroke on it. (NEWTON's Opt. Qu. 16.)

4. When any one turns round rapidly on one foot, till he becomes dizzy and falls upon the ground, the ſpectra of the ambient objects continue to preſent themſelves in rotation, or appear to librate, and he ſeems to behold them for ſome time ſtill in motion.

From all theſe experiments it appears, that the ſpectra in the eye are not owing to the mechanical impulſe of light impreſſed on the retina, nor to its chemical combination with that organ, nor to the abſorption and emiſſion of light, as is obſerved in many bodies: for in all theſe caſes the ſpectra muſt either remain uniformly, or gradually diminiſh; and neither their alternate preſence and evaneſcence as in the firſt experiment, nor the perpetual changes of their colours as in the ſecond, nor the flaſh of light or colours in the preſſed eye as in the third, nor the rotation or libration of the ſpectra as in the fourth, could exiſt.

It is not abſurd to conceive, that the retina may be ſtimulated into motion, as well as the red and white muſcles which form our limbs and veſſels; ſince it conſiſts of fibres, like thoſe, intermixed with its medullary ſubſtance. To evince this ſtructure, the retina of an ox's eye was ſuſpended in a glaſs of warm water, and forcibly torn in a few places; the edges of theſe parts appeared jagged and hairy, and did not contract, and become ſmooth like ſimple mucus, when it is diſtended till it breaks; which ſhews that it conſiſts of fibres; and this its fibrous conſtruction became ſtill more diſtinct to the ſight, by adding ſome cauſtic alkali to the water, as the adhering mucus was firſt eroded, and the hair-like fibres remained floating in the veſſel. Nor does the degree of tranſparency of the retina invalidate the evidence of its fibrous ſtructure, ſince LEEUWENHOEK has ſhewn that the cryſtalline humour itſelf conſiſts of fibres. (Arcana Naturæ, V. 1. p. 70.)

Hence it appears, that as the muſcles have larger fibres intermixed with a ſmaller quantity of nervous medulla, the organ of viſion has a greater quantity of nervous medulla intermixed with ſmaller fibres; and it is probable, that the locomotive muſcles, as well as the vaſcular ones, of microſcopic animals have much greater tenuity than theſe of the retina.

And beſides the ſimilar laws, which will be ſhewn in this Paper to govern alike the actions of the retina and of the muſcles, there are many other analogies which exiſt between them. They are both originally excited into action by irritations, both act nearly in the ſame quantity of time, are alike ſtrengthened or fatigued by exertion, are alike painful if excited into action when they are in an inflamed ſtate, are alike liable to paralyſis, and to the torpor of old age.

II. OF SPECTRA FROM DEFECT OF SENSIBILITY.

The retina is not ſo eaſily excited into action by leſs irritation after having been lately ſubjected to greater.

1. When any one paſſes from the bright daylight into a darkened room, the iriſes of his eyes expand themſelves to their utmoſt extent in a few ſeconds of time; but it is very long before the optic nerve, after having been ſtimulated by the greater light of the day, becomes ſenſible of the leſs degree of it in the room; and, if the room is not too obſcure, the iriſes will again contract themſelves in ſome degree, as the ſenſibility of the retina returns.

2. Place about half an inch ſquare of white paper on a black hat, and looking ſteadily on the center of it for a minute, remove your eyes to a ſheet of white paper; and after a ſecond or two a dark ſquare will be ſeen on the white paper, which will continue ſome time. A ſimilar dark ſquare will be ſeen in the cloſed eye, if light be admitted through the eye-lids.

So after looking at any luminous object of a ſmall ſize, as at the ſun, for a ſhort time, ſo as not much to fatigue the eyes, this part of the retina becomes leſs ſenſible to ſmaller quantities of light; hence, when the eyes are turned on other leſs luminous parts of the ſky, a dark ſpot is ſeen reſembling the ſhape of the ſun, or other luminous object which we laſt beheld. This is the ſource of one kind of the dark-coloured *muſcæ volitantes.* If this dark ſpot lies above the center of the eye, we turn our eyes that way, expecting to bring it into the center of the eye, that we may view it more diſtinctly; and in this caſe the dark ſpectrum ſeems to move upwards. If the dark ſpectrum is found beneath the center of the eye, we purſue it from the ſame motive, and it ſeems to move downwards. This has given riſe to various conjectures of ſomething floating in the aqueous humours of the eyes; but whoever, in attending to theſe ſpots, keeps his eyes unmoved by looking ſteadily at the corner of a cloud, at the ſame time that he obſerves the dark ſpectra, will be thoroughly convinced, that they have no motion but what is given to them by the movement of our eyes in purſuit of them. Sometimes the form of the ſpectrum, when it has been received from a circular luminous body, will become oblong; and ſometimes it will be divided into two circular ſpectra, which is owing to our changing the angle made by the two optic axiſes, according to the diſtance of the clouds or other bodies to which the ſpectrum is ſuppoſed to be contiguous. The apparent ſize of it will alſo be variable according to its ſuppoſed diſtance; but when ſuch a ſpectrum is received with only one eye, the other being covered, its form and number are invariable.

As theſe ſpectra are more eaſily obſervable when our eyes are a little weakened by fatigue, it has frequently happened, that people of delicate conſtitutions have been much alarmed at them, fearing a beginning decay of their ſight, and have thence fallen into the hands of ignorant oculiſts; but I believe they never are a prelude to any other diſeaſe of the eye, and that it is from habit alone, and our want of attention to them, that we do not ſee them on all objects every hour of our lives. But as the nerves of very weak people loſe their ſenſibility, in the ſame manner as their muſcles loſe their activity, by a ſmall time of exertion, it frequently happens, that ſick people in the extreme debility of fevers are perpetually employed in picking ſomething from the bed-cloaths, occaſioned by their miſtaking the appearance of theſe *muſcæ volitantes* in their eyes. BENVENUTO CELINI, an Italian artiſt, a man of ſtrong abilities, relates, that having paſſed the whole night on a diſtant mountain with ſome companions and a conjurer, and performed many ceremonies to raiſe the devil, on their return in the morning to Rome, and looking up when the ſun began to riſe, they ſaw numerous devils run on the tops of the houſes, as they paſſed along; ſo much were the ſpectra of their weakened eyes magnified by fear, and made ſubſervient to the purpoſes of fraud or ſuperſtition. (Life of BEN. CELINI.)

3. Place a ſquare inch of white paper on a large piece of ſtraw-coloured ſilk; look ſteadily ſome time on the white paper, and then move the center of your eyes on the ſilk, and a ſpectrum of the form of the paper will appear on the ſilk, of a deeper yellow than the other part of it: for the central part of the retina, having been ſome time expoſed to the ſtimulus of a greater quantity of white light, is become leſs ſenſible to a ſmaller quantity of it, and therefore ſees only the yellow rays in that part of the ſtraw-coloured ſilk.

Facts ſimilar to theſe are obſervable in other parts of our ſyſtem: thus, if one hand be made warm, and the other expoſed to the cold, and then both of them immerſed in ſubtepid water, the water is perceived warm to one hand, and cold to the other; and we are not able to hear weak ſounds for ſome time after we have been expoſed to loud ones; and we feel a chillineſs on coming into an atmoſphere of temperate warmth, after having been ſome time confined in a very warm room: and hence the ſtomach, and other organs of digeſtion, of thoſe who have been habituated to the greater ſtimulus of ſpirituous liquor, are not excited into their due action by the leſs ſtimulus of common food alone; of which the immediate conſequence is indigeſtion and hypochondriaciſm.

III. OF SPECTRA FROM EXCESS OF SENSIBILITY.

The retina is more eaſily excited into action by greater irritation after having been lately ſubjected to leſs.

1. If the eyes are cloſed, and covered perfectly with a hat, for a minute or two, in a bright day; on removing the hat a red or crimſon light is ſeen through the eye-lids. In this experiment the retina, after being ſome time kept in the dark, becomes ſo ſenſible to a ſmall quantity of light, as to perceive diſtinctly the greater quantity of red rays than of others which paſs through the eye-lids. A ſimilar coloured light is ſeen to paſs through the edges of the fingers, when the open hand is oppoſed to the flame of a candle.

2. If you look for ſome minutes ſteadily on a window in the beginning of the evening twilight, or in a dark day, and then move your eyes a little, ſo that thoſe parts of the retina, on which the dark frame-work of the window was delineated, may now fall on the glaſs part of it, many luminous lines, repreſenting the frame-work, will appear to lie acroſs the glaſs panes: for thoſe parts of the retina, which were before leaſt ſtimulated by the dark frame-work, are now more ſenſible to

light than the other parts of the retina which were expoſed to the more luminous parts of the window.

3. Make with ink on white paper a very black ſpot, about half an inch in diameter, with a tail about an inch in length, ſo as to repreſent a tadpole; look ſteadily for a minute on this ſpot, and, on moving the eye a little, the figure of the tadpole will be ſeen on the white part of the paper, which figure of the tadpole will appear whiter or more luminous than the other parts of the white paper; for the part of the retina on which the tadpole was delineated, is now more ſenſible to light than the other parts of it, which were expoſed to the white paper. This experiment is mentioned by Dr. IRWIN, but is not by him aſcribed to the true cauſe, namely, the greater ſenſibility of that part of the retina which has been expoſed to the black ſpot, than of the other parts which had received the white field of paper, which is put beyond a doubt by the next experiment.

4. On cloſing the eyes after viewing the black ſpot on the white paper, as in the foregoing experiment, a red ſpot is ſeen of the form of the black ſpot: for that part of the retina, on which the black ſpot was delineated, being now more ſenſible to light than the other parts of it, which were expoſed to the white paper, is capable of perceiving the red rays which penetrate the eyelids. If this experiment be made by the light of a tallow candle, the ſpot will be yellow inſtead of red; for tallow candles abound much with yellow light, which paſſes in greater quantity and force through the eyelids than blue light; hence the difficulty of diſtinguiſhing blue and green by this kind of candle light. The colour of the ſpectrum may poſſibly vary in the day light, according to the different colour of the meridian or the morning or evening light.

M. BEGUELIN, in the Berlin Memoires, V. II. 1771, obſerves, that, when he held a book ſo that the ſun ſhone upon his half cloſed eyelids, the black letters, which he had long inſpected, became red, which muſt have been thus occaſioned. Thoſe parts of the retina which had received for ſome time the black letters, were ſo much more ſenſible than thoſe parts which had been oppoſed to the white paper, that to the former the red light, which paſſed through the eyelids, was perceptible. There is a ſimilar ſtory told, I think, in M. DE VOLTAIRE's Hiſtorical Works, of a Duke of Tuſcany, who was playing at dice with the general of a foreign army, and, believing he ſaw bloody ſpots upon the dice, portended dreadful events, and retired in confuſion. The obſerver, after looking for a minute on the black ſpots of a die, and careleſſly cloſing his eyes, on a bright day, would ſee the image of a die with red ſpots upon it, as above explained.

5. On emerging from a dark cavern, where we have long continued, the light of a bright day becomes intolerable to the eye for a conſiderable time, owing to the exceſs of ſenſibility exiſting in the eye, after having been long expoſed to little or no ſtimulus. This occaſions us immediately to contract the iris to its ſmalleſt aperture, which becomes again gradually dilated, as the retina becomes accuſtomed to the greater ſtimulus of the daylight.

The twinkling of a bright ſtar, or of a diſtant candle in the night, is perhaps owing to the ſame cauſe. While we continue to look upon theſe luminous objects, their central parts gradually appear paler, owing to the decreaſing ſenſibility of the part of the retina expoſed to their light; whilſt, at the ſame time, by the unſteadineſs of the eye, the edges of them are perpetually falling on parts of the retina that were juſt before expoſed to the darkneſs of the night, and therefore tenfold more ſenſible to light than the part on which the ſtar or candle had been for ſome time delineated. This pains the eye in a ſimilar manner as when we come ſuddenly from a dark room into bright daylight, and gives the appearance of bright ſcintillations. Hence the ſtars twinkle moſt when the night is darkeſt, and do not twinkle through teleſcopes, as obſerved by MUSSCHENBROECK; and it will afterwards be ſeen why this twinkling is ſometimes of different colours when the object is very bright, as Mr. MELVILL obſerved in looking at Sirius. For the opinions of others on this ſubject, ſee Dr. PRIESTLEY's valuable Hiſtory of Light and Colours, p. 494.

Many facts obſervable in the animal ſyſtem are ſimilar to theſe; as the hot glow occaſioned by the uſual warmth of the air, or our cloaths, on coming out of a cold bath; the pain of the fingers on approaching the fire after having handled ſnow; and the inflamed heels from walking in ſnow. Hence thoſe who have been expoſed to much cold have died on being brought to a fire, or their limbs have become ſo much inflamed as to mortify. Hence much food or wine given ſuddenly to thoſe who have almoſt periſhed by hunger has deſtroyed them; for all the organs of the famiſhed body are now become ſo much more irritable to the ſtimulus of food and wine, which they have long been deprived of, that inflammation is excited, which terminates in gangrene or fever.

IV. OF DIRECT OCULAR SPECTRA.

A quantity of ſtimulus ſomewhat greater than natural excites the retina into ſpaſmodic action, which ceaſes in a few ſeconds.

A certain duration and energy of the ſtimulus of light and colours excites the perfect action of the retina in viſion; for very quick motions are imperceptible to us, as well as very ſlow ones, as the whirling of a top, or the ſhadow on a ſun-dial. So perfect darkneſs does not affect the eye at all; and exceſs of light produces pain, not viſion.

1. When a fire-coal is whirled round in the dark, a lucid circle remains a conſiderable time in the eye; and that with ſo much vivacity of light, that it is miſtaken for a continuance of the irritation of the object. In the ſame manner, when a fiery meteor ſhoots acroſs the night, it appears to leave a long lucid train behind it, part of which, and perhaps ſometimes the whole, is owing to the continuance of the action of the retina after having been thus vividly excited. This is beautifully illuſtrated by the following experiment: fix a paper ſail, three or four inches in diameter, and made like that of a ſmoke jack, in a tube of paſteboard; on looking through the tube at a diſtant proſpect, ſome disjointed parts of it will be ſeen through the narrow intervals between the ſails; but as the fly begins to revolve, theſe intervals appear larger; and when it revolves quicker, the whole proſpect is ſeen quite as diſtinct as if nothing intervened, though leſs luminous.

2. Look through a dark tube, about half a yard long, at the area of a yellow circle of half an inch diameter, lying upon a blue area of double that diameter, for half a minute;

and on cloſing your eyes the colours of the ſpectrum will appear ſimilar to the two areas, as in fig. 3.; but if the eye is kept too long upon them, the colours of the ſpectrum will be the reverſe of thoſe upon the paper, that is, the internal circle will become blue, and the external area yellow; hence ſome attention is required in making this experiment.

3. Place the bright flame of a ſpermaceti candle before a black object in the night; look ſteadily at it for a ſhort time, till it is obſerved to become ſomewhat paler; and on cloſing the eyes, and covering them carefully, but not ſo as to compreſs them, the image of the blazing candle will continue diſtinctly to be viſible.

4. Look ſteadily, for a ſhort time, at a window in a dark day, as in Exp. 2. S. III. and then cloſing your eyes, and covering them with your hands, an exact delineation of the window remains for ſome time viſible in the eye. This experiment requires a little practice to make it ſucceed well; ſince, if the eyes are fatigued by looking too long on the window, or the day be too bright, the luminous parts of the window will appear dark in the ſpectrum, and the dark parts of the framework will appear luminous, as in Exp. 2. S. III. And it is even difficult for many, who firſt try this experiment, to perceive the ſpectrum at all; for any hurry of mind, or even too great attention to the ſpectrum itſelf, will diſappoint them, till they have had a little experience in attending to ſuch ſmall ſenſations.

The ſpectra deſcribed in this ſection, termed direct ocular ſpectra, are produced without much fatigue of the eye; the irritation of the luminous object being ſoon withdrawn, or its quantity of light being not ſo great as to produce any degree of uneaſineſs in the organ of viſion; which diſtinguiſhes them from the next claſs of ocular ſpectra, which are the conſequence of fatigue. Theſe direct ſpectra are beſt obſerved in ſuch circumſtances that no light, but what comes from the object, can fall upon the eye; as in looking through a tube, of half a yard long, and an inch wide, at a yellow paper on the ſide of a room, the direct ſpectrum was eaſily produced on cloſing the eye without taking it from the tube: but if the lateral light is admitted through the eye-lids, or by throwing the ſpectrum on white paper, it becomes a reverſe ſpectrum, as will be explained below.

The other ſenſes alſo retain for a time the impreſſions that have been made upon them, or the actions they have been excited into. So if a hard body is preſſed upon the palm of the hand, as is practiſed in tricks of legerdemain, it is not eaſy to diſtinguiſh for a few ſeconds whether it remains or is removed; and taſtes continue long to exiſt vividly in the mouth, as the ſmoke of tobacco, or the taſte of gentian, after the ſapid material is withdrawn.

V. *A quantity of ſtimulus ſomewhat greater than the laſt mentioned excites the retina into ſpaſmodic action, which ceaſes and recurs alternately.*

1. On looking for a time on the ſetting ſun, ſo as not greatly to fatigue the ſight, a yellow ſpectrum is ſeen when the eyes are cloſed and covered, which continues for a time, and then diſappears, and recurs repeatedly before it intirely vaniſhes. This yellow ſpectrum of the ſun when the eye-lids are opened becomes blue; and if it is made to fall on the green graſs, or on other coloured objects, it varies its own

colour by an intermixture of theirs, as will be explained in another place.

2. Place a lighted ſpermaceti candle in the night about one foot from your eye, and look ſteadily on the center of the flame, till your eye becomes much more fatigued than in S. IV. Exp. 3.; and on cloſing your eyes a reddiſh ſpectrum will be perceived, which will ceaſe and return alternately.

The action of vomiting in like manner ceaſes, and is renewed by intervals, although the emetic drug is thrown up with the firſt effort: ſo after-pains continue ſome time after parturition; and the alternate pulſations of the heart of a viper are renewed for ſome time after it is cleared from its blood.

VI. OF REVERSE OCULAR SPECTRA.

The retina after having been excited into action by a ſtimulus ſomewhat greater than the laſt mentioned falls into oppoſite ſpaſmodic action.

The actions of every part of animal bodies may be advantageouſly compared with each other. This ſtrict analogy contributes much to the inveſtigation of truth; while thoſe looſer analogies, which compare the phænomena of animal life with thoſe of chemiſtry or mechanics, only ſerve to miſlead our inquiries.

When any of our larger muſcles have been in long or in violent action, and their antagoniſts have been at the ſame time extended, as ſoon as the action of the former ceaſes, the limb is ſtretched the contrary way for our eaſe, and a pandiculation or yawning takes place.

By the following obſervations it appears, that a ſimilar circumſtance obtains in the organ of viſion; after it has been fatigued by one kind of action, it ſpontaneouſly falls into the oppoſite kind.

1. Place a piece of coloured ſilk, about an inch in diameter, on a ſheet of white paper, about half a yard from your eyes; look ſteadily upon it for a minute; then remove your eyes upon another part of the white paper, and a ſpectrum will be ſeen of the form of the ſilk thus inſpected, but of a colour oppoſite to it. A ſpectrum nearly ſimilar will appear if the eyes are cloſed, and the eyelids ſhaded by approaching the hand near them, ſo as to permit ſome but to prevent too much light falling on them.

Red ſilk produced a green ſpectrum.
Green produced a red one.
Orange produced blue.
Blue produced orange.
Yellow produced violet.
Violet produced yellow.

That in theſe experiments the colours of the ſpectra are the reverſe of the colours which occaſioned them, may be ſeen by examining the third figure in Sir ISAAC NEWTON's Optics, L. II. p. 1. where thoſe thin laminæ of air, which reflected yellow, tranſmitted violet; thoſe which reflected red, tranſmitted a blue-green; and ſo of the reſt, agreeing with the experiments above related.

2. Theſe reverſe ſpectra are ſimilar to a colour, formed by a combination of all the primary colours except that with which the eye has been fatigued in making the experiment: thus the reverſe ſpectrum of red muſt be ſuch a green as would be produced by a combination of all the other priſmatic colours.

To evince this fact the following ſatisfactory experiment was made. The priſmatic colours were laid on a circular paſteboard wheel, about four inches in diameter, in the proportions deſcribed in Dr. PRIESTLEY's Hiſtory of Light and Colours, pl. 12. fig. 83. except that the red compartment was intirely left out, and the others proportionably extended ſo as to complete the circle. Then, as the orange is a mixture of red and yellow, and as the violet is a mixture of red and indigo, it became neceſſary to put yellow on the wheel inſtead of orange, and indigo inſtead of violet, that the experiment might more exactly quadrate with the theory it was deſigned to eſtabliſh or confute; becauſe in gaining a green ſpectrum from a red object, the eye is ſuppoſed to have become inſenſible to red light. This wheel, by means of an axis, was made to whirl like a top; and on its being put in motion, a green colour was produced, correſponding with great exactneſs to the reverſe ſpectrum of red.

3. In contemplating any one of theſe reverſe ſpectra in the cloſed and covered eye, it diſappears and re-appears ſeveral times ſucceſſively, till at length it intirely vaniſhes, like the direct ſpectra in ſect. v.; but with this additional circumſtance, that when the ſpectrum becomes faint or evaneſcent, it is inſtantly revived by removing the hand from before the eyelids, ſo as to admit more light: becauſe then not only the fatigued part of the retina is inclined ſpontaneouſly to fall into motions of a contrary direction, but being ſtill ſenſible to all other rays of light, except that with which it was lately fatigued, is by theſe rays at the ſame time ſtimulated into thoſe motions which form the reverſe ſpectrum.

From theſe experiments there is reaſon to conclude, that the fatigued part of the retina throws itſelf into a contrary mode of action, like oſcitation or pandiculation, as ſoon as the ſtimulus which has fatigued it is withdrawn; and that it ſtill remains ſenſible, that is, liable to be excited into action by any other colours at the ſame time, except the colour with which it has been fatigued.

VII. *The retina after having been excited into action by a ſtimulus ſomewhat greater than the laſt mentioned falls into various ſucceſſive ſpaſmodic actions.*

1. On looking at the meridian ſun as long as the eyes can well bear its brightneſs, the diſc firſt becomes pale, with a luminous creſcent, which ſeems to librate from one edge of it to the other, owing to the unſteadineſs of the eye; then the whole phaſis of the ſun becomes blue, ſurrounded with a white halo; and on cloſing the eyes, and covering them with the hands, a yellow ſpectrum is ſeen, which in a little time changes into a blue one.

M. DE LA HIRE obſerved, after looking at the bright ſun, that the impreſſion in his eye firſt aſſumed a yellow appearance, and then green, and then blue; and wiſhes to aſcribe theſe appearances to ſome affection of the nerves. (PORTERFIELD on the Eye, Vol. I. p. 343.)

2. After looking ſteadily on about an inch ſquare of pink ſilk, placed on white paper, in a bright ſunſhine, at the diſtance of a foot from my eyes, and cloſing and covering my eyelids, the ſpectrum of the ſilk was at firſt a dark green, and the ſpectrum of the white paper became of a pink. The ſpectra then both diſappeared; and then the internal ſpectrum was blue; and then, after a ſecond diſappearance, became yellow,

and laſtly pink, whilſt the ſpectrum of the field varied into red and green.

Theſe ſucceſſions of different coloured ſpectra were not exactly the ſame in the different experiments, though obſerved, as near as could be, with the ſame quantity of light, and other ſimilar circumſtances; owing, I ſuppoſe, to trying too many experiments at a time; ſo that the eye was not quite free from the ſpectra of the colours which were previouſly attended to.

The alternate exertions of the retina in the preceding ſection reſembled the oſcitation or pandiculation of the muſcles, as they were performed in directions contrary to each other, and were the conſequence of fatigue rather than of pain. And in this they differ from the ſucceſſive diſſimilar exertions of the retina, mentioned in this ſection, which reſemble in miniature the more violent agitations of the limbs in convulſive diſeaſes, as epilepſy, chorea S. Viti, and opiſthotonos; all which diſeaſes are perhaps, at firſt, the conſequence of pain, and have their periods afterwards eſtabliſhed by habit.

VIII. *The retina, after having been excited into action by a ſtimulus ſomewhat greater than the laſt mentioned, falls into a fixed ſpaſmodic action, which continues for ſome days.*

1. After having looked long at the meridian ſun, in making ſome of the preceding experiments, till the diſcs faded into a pale blue, I frequently obſerved a bright blue ſpectrum of the ſun on other objects all the next and the ſucceeding day, which conſtantly occurred when I attended to it, and frequently when I did not previouſly attend to it. When I cloſed and covered

my eyes, this appeared of a dull yellow; and at other times mixed with the colours of other objects on which it was thrown. *It may be imagined, that this part of the retina* was become inſenſible to white light, and thence a bluiſh ſpectrum became viſible on all luminous objects; but as a yellowiſh ſpectrum was alſo ſeen in the cloſed and covered eye, there can remain no doubt of this being the ſpectrum of the ſun. A ſimilar appearance was obſerved by M. ÆPINUS, which he acknowledges he could give no account of. (Nov. Com. Petrop. V. 10, p. 2. and 6.)

The locked jaw, and ſome cataleptic ſpaſms, are reſembled by this phænomenon; and from hence we may learn the danger to the eye by inſpecting very luminous objects too long a time.

IX. *A quantity of ſtimulus greater than the preceding induces a temporary paralyſis of the organ of viſion.*

1. Place a circular piece of bright red ſilk, about half an inch in diameter, on the middle of a ſheet of white paper; lay them on the floor in a bright ſunſhine, and fixing your eyes ſteadily on the center of the red circle, for three or four minutes, at the diſtance of four or ſix feet from the object, the red ſilk will gradually become paler, and finally ceaſe to appear red at all.

2. Similar to theſe are many other animal facts; as purges, opiates, and even poiſons, and contagious matter, ceaſe to ſtimulate our ſyſtem, after we have been habituated to their uſe. So ſome people ſleep undiſturbed by a clock, or even by a forge hammer in their neighbourhood: and not only continued irritations, but violent exertions of any kind, are ſucceeded

by temporary paralyſis. The arm drops down after violent action, and continues for a time uſeleſs; and it is probable, that thoſe who have periſhed ſuddenly in ſwimming, or in ſcating on the ice, have owed their deaths to the paralyſis, or extreme fatigue, which ſucceeds every violent and continued exertion.

X. MISCELLANEOUS REMARKS.

There were ſome circumſtances occurred in making theſe experiments, which were liable to alter the reſults of them, and which I ſhall here mention for the aſſiſtance of others, who may wiſh to repeat them.

1. *Of direct and inverſe ſpectra exiſting at the ſame time; of reciprocal direct ſpectra; of a combination of direct and inverſe ſpectra; of a ſpectral halo; rules to pre-determine the colours of ſpectra.*

a. When an area, about ſix inches ſquare, of bright pink Indian paper, had been viewed on an area, about a foot ſquare, of white writing paper, the internal ſpectrum in the cloſed eye was green, being the reverſe ſpectrum of the pink paper; and the external ſpectrum was pink, being the direct ſpectrum of the pink paper. The ſame circumſtance happened when the internal area was white, and external one pink; that is, the internal ſpectrum was pink, and the external one green. All the ſame appearances occurred when the pink paper was laid on a black hat.

b. When ſix inches ſquare of deep violet poliſhed paper was viewed on a foot ſquare of white writing paper, the internal ſpectrum was yellow, being the reverſe ſpectrum of the violet paper, *and the external one was violet,* being the direct ſpectrum of the violet paper.

c. When ſix inches ſquare of pink paper was viewed on a foot ſquare of blue paper, the internal ſpectrum was blue, and the external ſpectrum was pink; that is, the internal one was the direct ſpectrum of the external object, and the external one was the direct ſpectrum of the internal object, inſtead of their being each the reverſe ſpectrum of the objects they belonged to.

d. When ſix inches ſquare of blue paper were viewed on a foot ſquare of yellow paper, the interior ſpectrum became a brilliant yellow, and the exterior one a brilliant blue. The vivacity of the ſpectra was owing to their being excited both by the ſtimulus of the interior and exterior objects; ſo that the interior yellow ſpectrum was both the reverſe ſpectrum of the blue paper, and the direct one of the yellow paper; and the exterior blue ſpectrum was both the reverſe ſpectrum of the yellow paper, and the direct one of the blue paper.

e. When the internal area was only a ſquare half-inch of red paper, laid on a ſquare foot of dark violet paper, the internal ſpectrum was green, with a reddiſh-blue halo. When the red internal paper was two inches ſquare, the internal ſpectrum was a deeper green, and the external one redder. When the internal paper was ſix inches ſquare, the ſpectrum of it became blue, and the ſpectrum of the external paper was red.

f. When a ſquare half-inch of blue paper was laid on a ſix-inch ſquare of yellow paper, the ſpectrum of the central paper in the cloſed eye was yellow, incircled with a blue halo. On looking long on the meridian ſun, the diſc fades into a pale blue ſurrounded with a whitiſh halo.

Theſe circumſtances, though they very much perplexed the experiments till they were inveſtigated, admit of a ſatisfactory explanation; for while the rays from the bright internal object in exp. *a.* fall with their full force on the center of the retina, and, by fatiguing that part of it, induce the reverſe ſpectrum, many ſcattered rays, from the ſame internal pink paper, fall on the more external parts of the retina, but not in ſuch quantity as to occaſion much fatigue, and hence induce the direct ſpectrum of the pink colour in thoſe parts of the eye. The ſame reverſe and direct ſpectra occur from the violet paper in exp. *b.*: and in exp. *c.* the ſcattered rays from the central pink paper produce a direct ſpectrum of this colour on the external parts of the eye, while the ſcattered rays from the external blue paper produce a direct ſpectrum of that colour on the central part of the eye, inſtead of theſe parts of the retina falling reciprocally into their reverſe ſpectra. In exp. *d.* the colours being the reverſe of each other, the ſcattered rays from the exterior object falling on the central parts of the eye, and there exciting their direct ſpectrum, at the ſame time that the retina was excited into a reverſe ſpectrum by the central object, and this direct and reverſe ſpectrum being of ſimilar colour, the ſuperior brilliancy of this ſpectrum was produced. In exp. *e.* the effect of various quantities of ſtimulus on the retina, from the different reſpective ſizes of the internal and external areas, induced a ſpectrum of the internal area in the center of the eye, combined of the reverſe ſpectrum of that internal area and the direct one of the external area, in various ſhades of colour, from a pale green to a deep blue, with ſimilar changes in the ſpectrum of the external area. For the ſame reaſons, when an internal bright object was ſmall, as in exp. *f.* inſtead of the whole of the ſpectrum of the external object being reverſe to the colour of the internal object, only a kind of halo, or radiation of colour, ſimilar to that of the internal object, was ſpread a little way on the external ſpectrum. For this internal blue area being ſo ſmall, the ſcattered rays from it extended but a little way on the image of the external area of yellow paper, and could therefore produce only a blue halo round the yellow ſpectrum in the center.

If any one ſhould ſuſpect that the ſcattered rays from the exterior coloured object do not intermix with the rays from the interior coloured object, and thus affect the central part of the eye, let him look through an opake tube, about two feet in length, and an inch in diameter, at a coloured wall of a room with one eye, and with the other eye naked; and he will find, that by ſhutting out the lateral light, the area of the wall ſeen through a tube appears as if illuminated by the ſunſhine, compared with the other parts of it; from whence ariſes the advantage of looking through a dark tube at diſtant paintings.

Hence we may ſafely deduce the following rules to determine before-hand the colours of all ſpectra. 1. *The direct ſpectrum* without any lateral light is an evaneſcent repreſentation of its object in the unfatigued eye. 2. With ſome lateral light it becomes of a colour combined of the direct ſpectrum of the central object, and of the circumjacent objects, in proportion to their reſpective quantity and brilliancy. 3. The *reverſe ſpectrum* without lateral light is a repreſentation in the fatigued eye of the form of its objects, with ſuch a colour as would be produced by all the primary colours, except that of the object. 4. With lateral light the colour is compounded of the reverſe ſpectrum of the central object, and the direct ſpectrum of the circumjacent objects, in proportion to their reſpective quantity and brilliancy.

II. *Variation and vivacity of the ſpectra occaſioned by extraneous light.*

The reverſe ſpectrum, as has been before explained, is ſimilar to a colour, formed by a combination of all the primary colours, except that with which the eye has been fatigued in making the experiment: ſo the reverſe ſpectrum of red is ſuch a green as would be produced by a combination of all the other priſmatic colours. Now it muſt be obſerved, that this reverſe ſpectrum of red is therefore the direct ſpectrum of a combination of all the other priſmatic colours, except the red; whence, on removing the eye from a piece of red ſilk to a ſheet of white paper, the green ſpectrum, which is perceived, may either be called the reverſe ſpectrum of the red ſilk, or the direct ſpectrum of all the rays from the white paper, except the red; for in truth it is both. Hence we ſee the reaſon why it is not eaſy to gain a direct ſpectrum of any coloured object in the day-time, where there is much lateral light, except of very bright objects, as of the ſetting ſun, or by looking through an opake tube; becauſe the lateral external light falling alſo on the central part of the retina, contributes to induce the reverſe ſpectrum, which is at the ſame time the direct ſpectrum of that lateral light, deducting only the colour of the central object which we have been viewing. And for the ſame reaſon, it is difficult to gain the reverſe ſpectrum, where there is no lateral light to contribute to its formation. Thus, in looking through an opake tube on a yellow wall, and cloſing my eye, without admitting any lateral light, the ſpectra were all at firſt yellow; but at length changed into blue. And on looking in the ſame manner on red paper, I did at length get a green ſpectrum; but they were all at firſt red ones: and the ſame after looking at a candle in the night.

The reverſe ſpectrum was formed with greater facility when the eye was thrown from the object on a ſheet of white paper, or when light was admitted through the cloſed eyelids; becauſe not only the fatigued part of the retina was inclined ſpontaneouſly to fall into motions of a contrary direction; but being ſtill ſenſible to all other rays of light except that with which it was lately fatigued, was by theſe rays ſtimulated at the ſame time into thoſe motions which form the reverſe ſpectrum. Hence, when the reverſe ſpectrum of any colour became faint, it was wonderfully revived by admitting more light through the eyelids, by removing the hand from before them: and hence, on covering the cloſed eyelids, the ſpectrum would often ceaſe for a time, till the retina became ſenſible to the ſtimulus of the ſmaller quantity of light, and then it recurred. Nor was the ſpectrum only changed in vivacity, or in degree, by this admiſſion of light through the eyelids; but it frequently happened, after having viewed bright objects, that the ſpectrum in the cloſed and covered eye was changed into a third ſpectrum, when light was admitted through the eyelids: which third ſpectrum was compoſed of ſuch colours as could paſs through the eyelids, except thoſe of the object. Thus, when an area of half an inch diameter of pink paper was viewed on a ſheet of white paper in the ſunſhine, the ſpectrum with cloſed and covered eyes was green; but on removing the hands from before the cloſed eyelids, the ſpectrum became yellow, and returned inſtantly again to green, as often as the hands were applied to cover the eyelids, or removed from them: for the retina being now inſenſible to red light, the yellow rays paſſing through the eyelids in greater quantity than the other colours, induced a yellow ſpectrum; whereas if the ſpectrum was thrown on white paper, with the eyes open, it became only a lighter green.

Though a certain quantity of light facilitates the formation of the reverſe ſpectrum, a greater quantity prevents its formation, as the more powerful ſtimulus excites even the fatigued parts of the eye into action; otherwiſe we ſhould ſee the ſpectrum of the laſt viewed object as often as we turn our eyes. Hence the reverſe ſpectra are beſt ſeen by gradually approaching the hand near the cloſed eyelids to a certain diſtance only, which muſt be varied with the brightneſs of the day, or the energy of the ſpectrum. Add to this, that all dark ſpectra, as black, blue, or green, if light be admitted through the eyelids, after they have been ſome time covered, give reddiſh ſpectra, for the reaſons given in ſect. III. exp. 1.

From theſe circumſtances of the extraneous light coinciding with the ſpontaneous efforts of the fatigued retina to produce a reverſe ſpectrum, as was obſerved before, it is not eaſy to gain a direct ſpectrum, except of objects brighter than the ambient light; ſuch as a candle in the night, the ſetting ſun, or viewing a bright object through an opake tube; and then the reverſe ſpectrum is inſtantaneouſly produced by the admiſſion of ſome external light; and is as inſtantly converted again to the direct ſpectrum by the excluſion of it. Thus, on looking at the ſetting ſun, on cloſing the eyes, and covering them, a yellow ſpectrum is ſeen, which is the direct ſpectrum of the ſetting ſun; but on opening the eyes on the ſky, the yellow ſpectrum is immediately changed into a blue one, which is the reverſe ſpectrum of the yellow ſun, or the direct ſpectrum of the blue ſky, or a combination of both. And this is again transformed into a yellow one on cloſing the eyes, and ſo reciprocally, as quick as the motions of the opening and cloſing eyelids. Hence, when Mr. MELVILL obſerved the ſcintillations of the ſtar Sirius to be ſometimes coloured, theſe were probably the direct ſpectrum of the blue ſky on the parts of the retina fatigued by the white light of the ſtar. (Eſſays Phyſical and Literary, p. 81. V. 2.)

When a direct ſpectrum is thrown on colours darker than itſelf, it mixes with them; as the yellow ſpectrum of the ſetting ſun, thrown on the green graſs, becomes a greener yellow. But when a direct ſpectrum is thrown on colours brighter than itſelf, it becomes inſtantly changed into the reverſe ſpectrum, which mixes with thoſe brighter colours. So the yellow ſpectrum of the ſetting ſun thrown on the luminous ſky becomes blue, and changes with the colour or brightneſs of the clouds on which it appears. But the reverſe ſpectrum mixes with every kind of colour on which it is thrown, whether brighter than itſelf or not: thus the reverſe ſpectrum, obtained by viewing a piece of yellow ſilk, when thrown on white paper was a lucid blue green; when thrown on black Turkey leather becomes a deep violet. And the ſpectrum of blue ſilk, thrown on white paper, was a light yellow; on black ſilk was an obſcure orange; and the blue ſpectrum, obtained from orange-coloured ſilk, thrown on yellow, became a green.

In theſe caſes the retina is thrown into activity or ſenſation by the ſtimulus of external colours, at the ſame time that it continues the activity or ſenſation which forms the ſpectra; in the ſame manner as the priſmatic colours, painted on a whirling top, are ſeen to mix together. When theſe colours of external objects are brighter than the direct ſpectrum which is thrown upon them, they change it into the reverſe ſpectrum, like the admiſſion of external light on a direct ſpectrum, as explained above. When they are darker than the direct ſpectrum, they mix with it, their weaker ſtimulus being inſufficient to induce the reverſe ſpectrum.

III. *Variation of ſpectra in reſpect to number and figure and remiſſion.*

When we look long and attentively at any object, the eye cannot always be kept intirely motionleſs; hence, on inſpecting a circular area of red ſilk placed on white paper, a lucid creſcent or edge is ſeen to librate on one ſide or other of the red circle: for the exterior parts of the retina ſometimes falling on the edge of the central ſilk, and ſometimes on the white paper, are leſs fatigued with red light than the central part of the retina, which is conſtantly expoſed to it; and therefore, when they fall on the edge of the red ſilk, they perceive it more vividly. Afterwards, when the eye becomes fatigued, a green ſpectrum in the form of a creſcent is ſeen to librate on one ſide or other of the central circle, as by the unſteadineſs of the eye a part of the fatigued retina falls on the white paper; and as by the increaſing fatigue of the eye the central part of the ſilk appears paler, the edge on which the unfatigued part of the retina occaſionally falls will appear of a deeper red than the original ſilk, becauſe it is compared with the pale internal part of it. M. DE BUFFON in making this experiment obſerved, that the red edge of the ſilk was not only deeper coloured than the original ſilk; but, on his retreating a little from it, it became oblong, and at length divided into two, which muſt have been owing to a change of the angle of the two optic axiſes with the new diſtance he obſerved it at. Thus, if a pen is held up before a diſtant candle, when we look intenſely at the pen two candles are ſeen behind it; when we look intenſely at the candle two pens are ſeen. If the ſight be unſteady at the time of beholding the ſun, even though one eye only be uſed, many images of the ſun will appear, or luminous lines, when the eye is cloſed. And as ſome parts of theſe will be more vivid than others, and ſome parts of them will be produced nearer the center of the eye than others, theſe will diſappear ſooner than the others; and hence the number and ſhape of theſe ſpectra of the ſun will continually vary, as long as they exiſt. The cauſe of ſome being more vivid than others, is the unſteadineſs of the eye of the beholder, ſo that ſome parts of the retina have been longer expoſed to the ſunbeams. That ſome parts of a complicated ſpectrum fade and return before other parts of it, the following experiment evinces. Draw three concentric circles; the external one an inch and a half in diameter, the middle one an inch, and the internal one half an inch; colour the external and internal areas blue, and the remaining one yellow, as in fig. 4.; after having looked about a minute on the center of theſe circles, in a bright light, the ſpectrum of the external area appears firſt in the cloſed eye, then the middle area, and laſtly the central one; and then the central one diſappears, and the others in inverted order. If concentric circles of more colours are added, it produces the beautiful ever changing ſpectrum in ſect. I. exp. 2.

From hence it would ſeem, that the center of the eye produces quicker remiſſions of ſpectra, owing perhaps to its greater ſenſibility; that is, to its more energetic exertions. Theſe remiſſions of ſpectra bear ſome analogy to the tremors of the hands, and palpitations of the heart, of weak people: and perhaps a criterion of the ſtrength of any muſcle or nerve may be taken from the time it can be continued in exertion.

IV. *Variation of ſpectra in reſpect to brilliancy; the viſibility of the circulation of the blood in the eye.*

1. The meridian or evening light makes a difference in the colours of ſome ſpectra; for as the ſun deſcends, the red rays, which are leſs refrangible by the convex atmoſphere, abound in great quantity. Whence the ſpectrum of the light parts of a window at this time, or early in the morning, is red; and becomes blue either a little later or earlier; and white in the meridian day; and is alſo variable from the colour of the clouds or ſky which are oppoſed to the window.

2. All theſe experiments are liable to be confounded, if they are made too ſoon after each other, as the remaining ſpectrum will mix with the new ones. This is a very troubleſome circumſtance to painters, who are obliged to look long upon the ſame colour; and in particular to thoſe whoſe eyes, from natural debility, cannot long continue the ſame kind of exertion. For the ſame reaſon, in making theſe experiments, the reſult becomes much varied if the eyes, after viewing any object, are removed on other objects for but an inſtant of time, before we cloſe them to view the ſpectrum; for the light from the object, of which we had only a tranſient view, in the very time of cloſing our eyes acts as a ſtimulus on the fatigued retina; and for a time prevents the deſired ſpectrum from appearing, or mixes its own ſpectrum with it. Whence, after the eyelids are cloſed, either a dark field, or ſome unexpected colours, are beheld for a few ſeconds, before the deſired ſpectrum becomes diſtinctly viſible.

3. The length of time taken up in viewing an object, of which we are to obſerve the ſpectrum, makes a great difference

in the appearance of the ſpectrum, not only in its vivacity, but in its colour; as the direct ſpectrum of the central object, or of the circumjacent ones, and alſo the reverſe ſpectra of both, with their various combinations, as well as the time of their duration in the eye, and of their remiſſions or alternations, depend upon the degree of fatigue the retina is ſubjected to. The Chevalier D'ARCY conſtructed a machine by which a coal of fire was whirled round in the dark, and found, that when a luminous body made a revolution in eight thirds of time, it preſented to the eye a complete circle of fire; from whence he concludes, that the impreſſion continues on the organ about the ſeventh part of a ſecond. (Mém. de l'Acad. des Sc. 1765.) This, however, is only to be conſidered as the ſhorteſt time of the duration of theſe direct ſpectra; ſince in the fatigued eye both the direct and reverſe ſpectra, with their intermiſſions, appear to take up many ſeconds of time, and ſeem very variable in proportion to the circumſtances of fatigue or energy.

4. It ſometimes happens, if the eyeballs have been rubbed hard with the fingers, that lucid ſparks are ſeen in quick motion amidſt the ſpectrum we are attending to. This is ſimilar to the flaſhes of fire from a ſtroke on the eye in fighting, and is reſembled by the warmth and glow which appear upon the ſkin after friction, and is probably owing to an acceleration of the arterial blood into the veſſels emptied by the previous preſſure. By being accuſtomed to obſerve ſuch ſmall ſenſations in the eye, it is eaſy to ſee the circulation of the blood in this organ. I have attended to this frequently, when I have obſerved my eyes more than commonly ſenſible to other ſpectra. The circulation may be ſeen either in both eyes at a time, or only in one of them; for as a certain quantity of light is neceſſary

to produce this curious phænomenon, if one hand be brought nearer the cloſed eyelids than the other, the circulation in that eye will for a time diſappear. For the eaſier viewing the circulation, it is ſometimes neceſſary to rub the eyes with a certain degree of force after they are cloſed, and to hold the breath rather longer than is agreeable, which, by accumulating more blood in the eye, facilitates the experiment; but in general it may be ſeen diſtinctly after having examined other ſpectra with your back to the light, till the eyes become weary; then having covered your cloſed eyelids for half a minute, till the ſpectrum is faded away which you were examining, turn your face to the light, and removing your hands from the eyelids, by and by again ſhade them a little, and the circulation becomes curiouſly diſtinct. The ſtreams of blood are however generally ſeen to unite, which ſhews it to be the venous circulation, owing, I ſuppoſe, to the greater opacity of the colour of the blood in theſe veſſels; for this venous circulation is alſo much more eaſily ſeen by the microſcope in the tail of a tadpole.

v. *Variation of ſpectra in reſpect to diſtinctneſs and ſize; with a new way of magnifying objects.*

1. It was before obſerved, that when the two colours viewed together were oppoſite to each other, as yellow and blue, red and green, &c. according to the table of reflections and tranſmiſſions of light in Sir ISAAC NEWTON's Optics, B. II. fig. 3. the ſpectra of thoſe colours were of all others the moſt brilliant, and beſt defined; becauſe they were combined of the reverſe ſpectrum of one colour, and of the direct ſpectrum of the other. Hence, in books printed with ſmall types, or in

the minute graduation of thermometers, or of clock-faces, which are to be ſeen at a diſtance, if the letters or figures are coloured with orange, and the ground with indigo; or the letters with red, and the ground with green; or any other lucid colour is uſed for the letters, the ſpectrum of which is ſimilar to the colour of the ground; ſuch letters will be ſeen much more diſtinctly, and with leſs confuſion, than in black or white: for as the ſpectrum of the letter is the ſame colour with the ground on which they are ſeen, the unſteadineſs of the eye in long attending to them will not produce coloured lines by the edges of the letters, which is the principal cauſe of their confuſion. The beauty of colours lying in vicinity to each other, whoſe ſpectra are thus reciprocally ſimilar to each colour, is owing to this greater eaſe that the eye experiences in beholding them diſtinctly; and it is probable, in the organ of hearing a ſimilar circumſtance may conſtitute the pleaſure of melody. Sir ISAAC NEWTON obſerves, that gold and indigo were agreeable when viewed together; and thinks there may be ſome analogy between the ſenſations of light and ſound. (Optics, Qu. 14.)

In viewing the ſpectra of bright objects, as of an area of red ſilk of half an inch diameter on white paper, it is eaſy to magnify it to tenfold its ſize: for if, when the ſpectrum is formed, you ſtill keep your eye fixed on the ſilk area, and remove it a few inches further from you, a green circle is ſeen round the red ſilk: for the angle now ſubtended by the ſilk is leſs than it was when the ſpectrum was formed, but that of the ſpectrum continues the ſame, and our imagination places them at the ſame diſtance. Thus when you view a ſpectrum on a ſheet of white paper, if you approach the paper to the eye, you may diminiſh it to a point; and if the paper is made to recede from the eye, the ſpectrum will appear magnified in proportion to the diſtance.

I was ſurpriſed, and agreeably amuſed, with the following experiment. I covered a paper about four inches ſquare with yellow, and with a pen filled with a blue colour wrote upon the middle of it the word BANKS in capitals, as in fig. 5. and, ſitting with my back to the ſun, fixed my eyes for a minute exactly on the center of the letter N in the middle of the word; after cloſing my eyes, and ſhading them ſomewhat with my hand, the word was diſtinctly ſeen in the ſpectrum in yellow letters on a blue field; and then, on opening my eyes on a yellowiſh wall at twenty feet diſtance, the magnified name of BANKS appeared written on the wall in golden characters.

CONCLUSION.

It was obſerved by the learned M. SAUVAGES (Noſol. method. Cl. VIII. Ord. 1.) that the pulſations of the optic artery might be perceived by looking attentively on a white wall well illuminated. A kind of net-work, darker than the other parts of the wall, appears and vaniſhes alternately with every pulſation. This change of the colour of the wall he well aſcribes to the compreſſion of the retina by the diaſtole of the artery. The various colours produced in the eye by the preſſure of the finger, or by a ſtroke on it, as mentioned by Sir ISAAC NEWTON, ſeem likewiſe to originate from the unequal preſſure on various parts of the retina. Now as Sir ISAAC NEWTON has ſhewn, that all the different colours are reflected or tranſmitted by the laminæ of ſoap bubbles, or of air, according to their different thickneſs or thinneſs, is it not probable, that the effect of the activity of the retina may be to alter its thickneſs or thinneſs, ſo as better to adapt it to reflect or tranſmit the colours which ſtimulate it into action? May not muſcular fibres exiſt in the retina for this purpoſe, which may be leſs minute than the locomotive muſcles of microſcopic animals? May not theſe muſcular actions of the retina conſtitute the ſenſation of lights and colours; and the voluntary repetitions of them, when the object is withdrawn, conſtitute our memory of them? And laſtly, may not the laws of the ſenſations of light, here inveſtigated, be applicable to all our other ſenſes, and much contribute to elucidate many phænomena of animal bodies both in their healthy and diſeaſed ſtate; and thus render this inveſtigation well worthy the attention of the phyſician, the metaphyſician, and the natural philoſopher?

Derby, November 1, 1785.

Fig. 1.

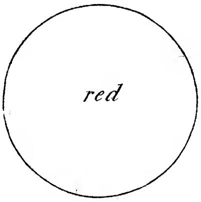


Fig. 3.

Fig. 2.

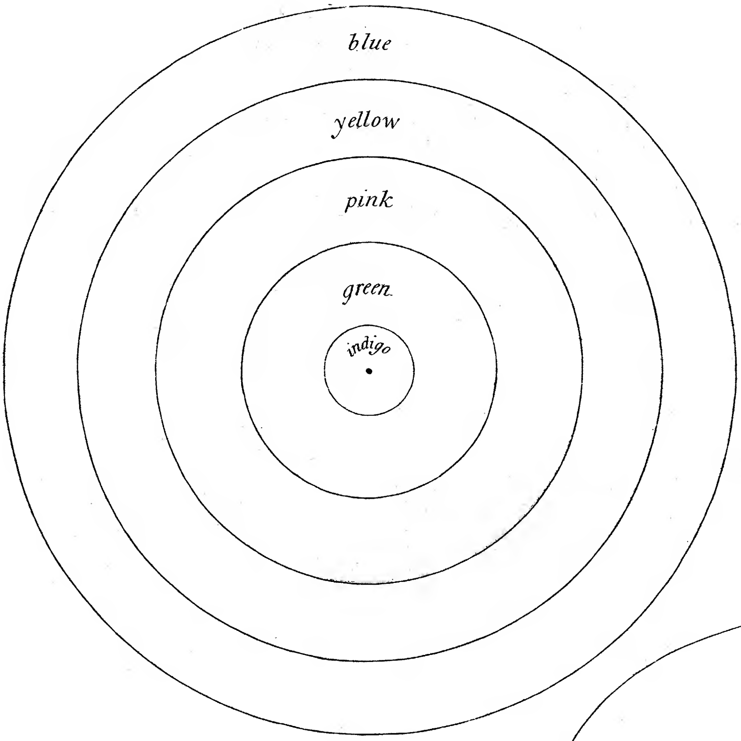


Fig. 4.

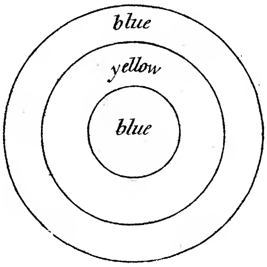
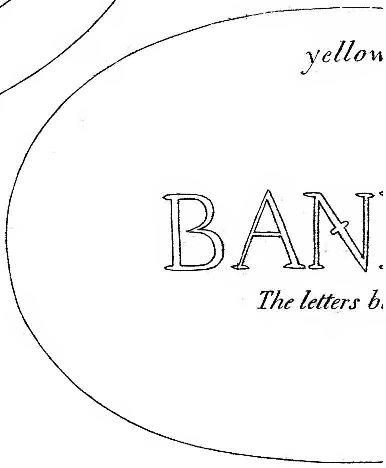


Fig. 5.



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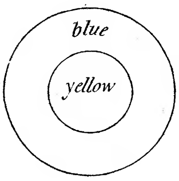

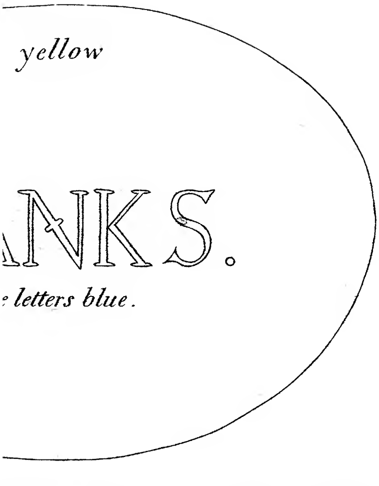

Fig. 1

Fig. 3

Fig. 2

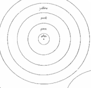

Fig. 4

Fig. 5